CLIMATE VARIABILITY INDUCED SHIFTS OF THE WAVE CLIMATE IN MEXICO

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INTRODUCTION

Inter-annual variability of wave climates is important for coastal risk assessment because these fluctuations can increase or decrease seasonal erosion risk (Wahl and Plant 2015). Understanding how long-term variability affects the seasonality of sediment transport is an important challenge in risk assessments (Toimil et al. 2020). There have been many attempts to quantify long-term variability in offshore wave climate, as this is the primary driver of coastal processes on sandy coasts. However, there is very little work on how the long-term variability of wave climate influences sediment transport. One of the most important drivers of sediment transport is the mean wave direction of incoming waves (Barnard et al. 2015; Hemer, Church, and Hunter 2010; Morim et al. 2019), although it is still not fully understood. An important contribution in this regard is the work of (Barnard et al. 2015), who found that El Niño Southern Oscillation (ENSO) dominates coastal vulnerability in the Pacific Ocean. On the other hand, several works at global scale (Godoi and Torres Júnior 2020; Reguero, Losada, and Méndez 2019; Stopa and Cheung 2014) have found that ENSO is the climatic driver that most affects the interannual variability of the wave climate. However, understanding how ENSO impacts wave direction is still lacking.

The present work aims to quantify the wave direction anomalies of the main wave climate types (Extra-Tropical Westerlies, Subtropical Southerlies, and Tropical Easterlies) that affect the coast of Mexico, and quantify the anomalies induced by ENSO. The work is based on the wave climate classification of Odériz et al. (2020). The anomalies in direction for each wave climate types were calculated, and the composite anomalies were calculated for the different phases of ENSO (El Niño and La Niña).

STUDY AREA

The present work focuses on four cases in Mexico where different wave climate types prevail. Ensenada, in the northwest, which is strongly influenced by Extratropical wave climate, Puerto Vallarta in the central west, and Acapulco in the southwest, both influenced by Extratropical and Subtropical wave climates. Finally, Puerto Morelos, in the southeast, which is strongly influenced by Tropical wave climate.

GLOBAL WAVE CLIMATE TYPES

In previous work, wave climates were classified (Odériz et al. 2020) into Extra-tropical, Subtropical and Tropical wave climates. Different mechanisms in the lower structure of the atmosphere generate these distinct wave climates and large scale atmospheric phenomena can be detected. The classification employs the k-mean and monthly mean wave direction and wave power. ERA 5 reanalysis was used, with hourly data and 0.5° x 0.5° spatial resolution for the period 1979-2018. The classification identified: Extra-Tropical high wave power Westerly (ETW), low wave power Tropical Easterly (TE), and moderate wave power Sub-Tropical Southerly (STS). Each climate exhibits variability in wave power and direction on a seasonal to inter-annual basis. The wave climates are shown in Figure 1. ETW covers the mid latitudes (± 30°, ± 60°) of the North Pacific (grey). TE affects the middle and west of the tropical Atlantic, associated with the Trade Winds (blue). STS is generated by the high pressure ridge of the Southern Hemisphere which produces the largest swells that propagate northward (beige). A detailed analysis of these wave climate types will be published shortly.

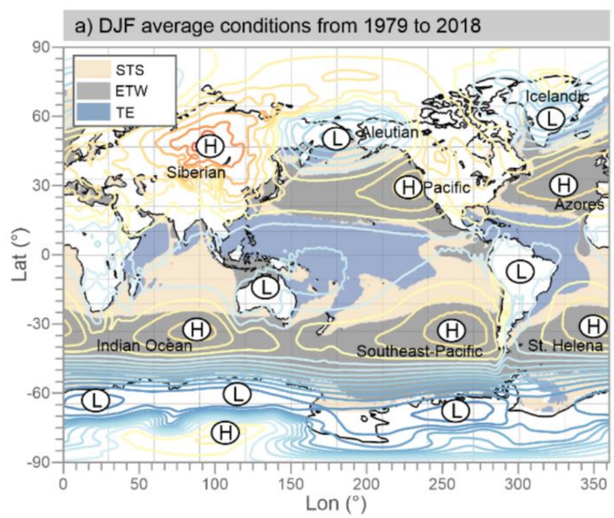

Figure 1 - sea level pressure (SLP) in winter (December, January and February, DJF), data from NCEP- CFSR (Saha, Suranjana 2010), and the mechanisms responsible for the wave climates from 1979 to 2018.

WAVE DIRECTION VARIABILITY FOR MEXICO

Odériz et al. (2020) carried out a detailed study of the wave climates on the Mexican coast. From this, four wave climate systems were identified:

1) Northwest (Pacific) coasts, where ETW prevails
2) Centre-west (Pacific) coasts, where both ETW, and STS influence waves and coastal hydrodynamics.
3) Southwest (Pacific) coasts, affected by STS and occasionally by ETW.

4) Caribbean coasts, where Tropical wave climate prevail.

Four cases studies (Ensenada, Puerto Vallarta, Acapulco, and Puerto Morelos) were selected, representative of each of these regions. The anomalies in wave direction were computed for each region and the directions were associated to each wave climate type, as shown in the wave roses of Figure 2 (a, c, f, i).

The monthly anomalies were calculated for each wave climate type: the wave direction minus the average of the mean direction of the corresponding month (Equation 1). To calculate the anomalies, only the values corresponding to each climate were considered.

$$DirA_{CT_n} = Dir_{CT_n} - \frac{1}{N}\sum_{i=0}^{i=N} Dir_{i_{CTn}}; n = 1,2,\dots,12; \mathrm{CT} = \mathrm{ETW, STS, TE}.$$

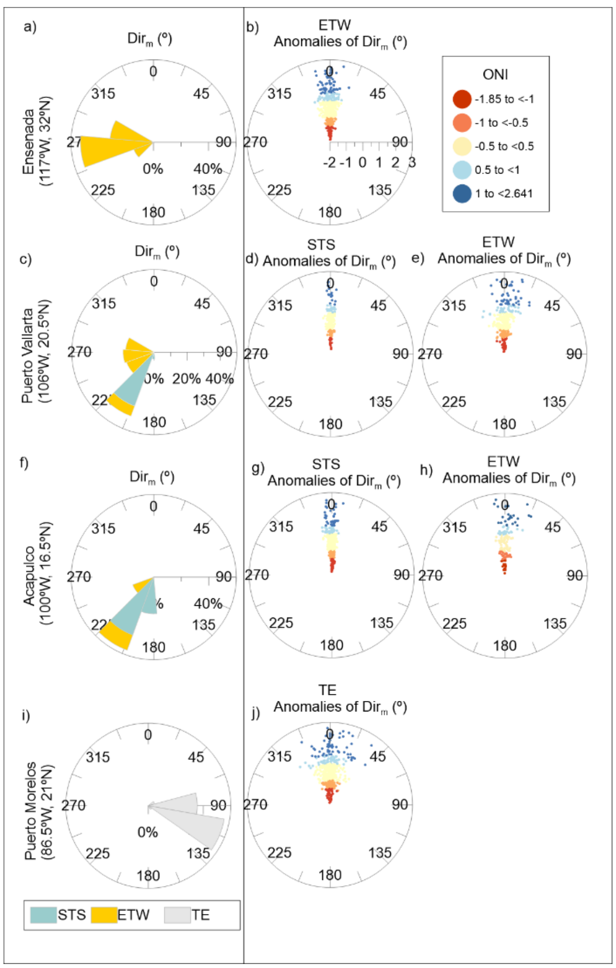

Figure 2. Wave direction means (a,c,f,i) and anomalies (b,d,e,g,h,j) for different wave climate types. Ensenada (a,b); Puerto Vallarta (c,d,e); Acapulco (f, g, h); Puerto Morelos (i,j). The mean direction follows meteorological convection.

Ensenada is permanently influenced by ETW with a range of anomalies in direction of ±20 º (Figure 4a). Puerto Vallarta and Acapulco are governed by both ETW and STS wave climates. However, the two wave climates overlap in Acapulco, with anomalies (-25°,22°), while, in Puerto Vallarta, ETW (-31°,31°) has more variability than STS (-11°,9°). Puerto Morelos has the greatest monthly variability in wave direction, ±40 º, induced by Tropical wave climate. This is probably because seasonally the Intertropical Convergence Zone shifts latitudinally. In general the anomalies presented by the Westerlies and Tropical climates are greater than the anomalies of the Southerlies. The Westerlies and Tropical wave climates depend on the relative positon of the High and Low pressure belts, and any changes in the position of either their centres can lead to shifts in the mean wave direction produced by these systems.

WAVE DIRECTION SHIFTS INDUCED BY ENSO

It is important to have an understanding of the variability of the directional wave climate, and atmospheric drivers over a range of time scales (i.e. seasonal to multi decadal) to evaluate coastal risk.

One of the most important drivers of wave climate is ENSO. Particularly, ENSO impacts the Extratropical Wave Climate in the North Pacific (Odériz 2020). At local scale, for each climate type, the wave direction composite anomalies for ENSO was computed, the phases of El Niño (ONI>=0.5) and La Niña (ONI<=-0.5) were considered.

The ETW in Ensenada and the TE in Puerto Morelos have opposite responses to ENSO in El Niño and La Niña phases, Table 1. The ETW in Puerto Vallarta and Acapulco shifts clockwise (anticlockwise) during El Niño (La Niña). Opposite is the response of wave direction to ENSO phases of STS type.

Table 1. Wave direction composite anomalies for ENSO.

	Ensenada		Puerto Vallarta		Acapulco		Puerto Morelos	
	EL Niño	La Niña	EL Niño	La Niña	EL Niño	La Niña	EL Niño	La Niña
STS	-	-	0.33	0.64	-1.01	1.61	-	-
ETW	-0.66	1.42	3.32	-1.91	3.22	-1.89	-	-
TE	-	-	-	-	-	-	0.88	-0.64

REFERENCES

Barnard, Short, Harley, Splinter, Vitousek, Turner, Allan, Banno, Bryan, Doria, Hansen, Kato, Kuriyama, Randall-Goodwin, Ruggiero, Walker, and Heathfield (2015): Coastal Vulnerability across the Pacific Dominated by El Niño/Southern Oscillation. Nature Geoscience 8(10):801-7.

Godoi, and Torres Júnior (2020): A Global Analysis of Austral Summer Ocean Wave Variability during SAM-ENSO Phase Combinations. Climate Dynamics 54(9):3991-4004.

Hemer, Church, and Hunter. 2010. “Variability and Trends in the Directional Wave Climate of the Southern Hemisphere. International Journal of Climatology 30(4):475-91.

Morim, Hemer, Wang, Cartwright, Trenham, Semedo, Young, Bricheno, Camus, Casas-Prat, Erikson, Mentaschi, Mori, Shimura, Timmermans, Aarnes, Breivik,

Behrens, Dobrynin, Menendez, Staneva, Wehner, Wolf, Kamranzad, Webb, Stopa, and Andutta (2019): Robustness and Uncertainties in Global Multivariate Wind-Wave Climate Projections. Nature Climate Change 9(9):711-18.
Odériz, Silva, Mortlock, and Mendoza (2020): Climate Drivers of Directional Wave Power on the Mexican Coast." Ocean Dynamics 70(9):1253–65.
Reguero, Losada, and Méndez (2019): A Recent Increase in Global Wave Power as a Consequence of Oceanic Warming. Nature Communications 10(1):1-14.
Saha, and Coauthors (2010): The NCEP Climate Forecast System Reanalysis. Bull. Amer. Meteor. Soc. 91:1015.1057.
Stopa, Fai Cheung (2014): Periodicity and Patterns of Ocean Wind and Wave Climate. Journal of Geophysical Research: Oceans 119(8):5563–84.
Toimil, Camus, Losada,Le Cozannet, Nicholls, Idier, and Maspataud (2020): Climate Change-Driven Coastal Erosion Modelling in Temperate Sandy Beaches: Methods and Uncertainty Treatment. Earth-Science Reviews 202:103110.
Wahl, and Plant (2015): Changes in Erosion and Flooding Risk Due to Long-Term and Cyclic Oceanographic Trends. Geophysical Research Letters 42(8):2943–50.